Forms of knowledge and eco-innovation modes: Evidence from Spanish manufacturing firms

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Forms of knowledge and eco-innovation modes:
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Abstract

The paper investigates the knowledge drivers of firms' eco-innovations (EI) by retaining the diverse nature of their target. Different internal and external knowledge sources are examined and the evidence of EI-modes is searched with respect to a sample of Spanish manufacturing firms covering the 2007-2009 and 2010-2012 periods. An "attenuated" Science, Technology, EI-mode prevails internally, with R&D more pivotal than either embodied or disembodied non-R&D knowledge, depending on the EI strategy. Externally, synthetic knowledge matters more than the analytical one, suggesting instead a Doing, Using, Interacting EI-mode. Hence, a dichotomic combination of the two modes emerges across the firm's boundaries. However, remarkable differences are in place, depending on whether EIs target efficiency or non-efficiency related environmental improvements. Our evidence also shows that internal and external knowledge turn out difficult to combine, both within and across modes.

JEL: Q55; O31; O32.
Keywords: Eco-innovation, knowledge, innovation modes, DUI, STI.

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1. Introduction

The socio-economic relevance of environmental innovations - hereafter EIs[1] - is nowadays undisputed (EC, 2010; Porter and van der Linde, 1995). The analysis of their drivers has accordingly become of paramount importance in academic research. In particular, a 'hybrid approach' (Rennings, 2000; Cleff and Rennings, 1999), in which environmental/ecological economics and innovation studies are integrated, has flourished. Within this approach, the analysis of "standard" innovation drivers is extended to EIs and combined with that of the "regulatory push/pull effect" of environmental policy (e.g. Canon de Francia et al., 2007; Wagner, 2007; Horbach, 2008; Kesidou and Demirel, 2012; Horbach et al., 2012).

Only recently, some focus has been placed on the different types of knowledge, competencies and resources that firms acquire/develop to become eco-innovators (e.g. De Marchi, 2012; De Marchi, and Grandinetti, 2013; Ketata et al., 2014; Ghisetti et al., 2015; Cainelli et al., 2015). In particular, an approach to these EI drivers has been privileged, which looks at the different significance and importance of an identified number of determinants – e.g. R&D and cooperation – between "generic" eco-innovators and non-eco-innovators. In spite of the interesting insights obtained with this analysis, some important questions have been marginalised and require a novel perspective to be adopted, as we propose in this paper.

First of all, the standard analysis does not consider that eco-innovators may distinguish from standard innovators also in the management of their portfolio of knowledge drivers. In particular, by relying on some knowledge sources rather/more than on others, both internally and externally, eco-innovators may follow different "eco-innovation modes", with respect to standard innovators (Evangelista and Vezzani, 2010). Referring to a popular distinction in innovation studies (Jensen et al., 2007), eco-innovators might show specific ways of following a Science, Technology, and Innovation (STI) mode, in brief a STEI mode, rather than a Doing, Using, and Interacting (DUI) mode (Jensen et al., 2007), that is a DUIEI mode, and of combining them across the firm's boundaries (e.g. Parrilli and Elola, 2012; Fitjar and Rodríguez-Pose, 2013; Gonzàlez Pernìa et al., 2015). The neglect of this issue is quite unfortunate, as its analysis could help the operationalisation of environmental policy/managerial action, as well as the academic debate on the radicalness of EIs, which also depends on their innovation modes (Jensen et al., 2007; Carrillo-Hermosilla et al., 2010). In order to address this important aspect, we thus propose a "systemic" approach to EI drivers: rather than looking at their differential impact with respect to standard innovations

[1] A standard definition of EI is provided by Kemp and Pontoglio (2007, p. 10) as "the production, assimilation or exploitation of a product, production process, service or management or business methods that is novel to [firms] and which results, through-out its life cycle, in a reduction of environmental risk, pollution and other negative impacts of resources use (including energy use) compared to relevant alternatives".

individually, we consider the different knowledge assets side by side in defining the firm's knowledge portfolio for EIs.

A second neglected aspect in the extant literature pertains to the heterogeneity of the EI strategies that firms can follow, for example, by adopting cleaner production technologies rather than end-of-pipe ones. So far, a basic comparative approach has limited the focus to their different techno-economic drivers and/or institutional/policy factors (e.g. Cleff and Rennings, 1999; Demirel and Kesidou, 2011; Horbach et al., 2012, 2103; Triguero et al., 2013). Little attention has instead been paid to the different knowledge needs and combinations entailed by specific EIs with respect to generic ones, losing sight of specific modes of eco-innovating within the same green realm. This is another important aspect to consider for an accurate policy and managerial action on EIs. Whenever theoretical and/or empirical arguments allow us to do so, we thus originally specify our arguments about general EI-modes by distinguishing at least two more refined classes of EIs: efficiency related, like material and/or energy saving technologies, and non-efficiency related, like end-of-pipe solutions and new green products.

In order to implement this new approach, we put forward some research hypotheses about the significance and relative importance that different forms of internally generated and externally acquired knowledge have for the firm's EI strategies, in general and in the two EI domains that we retain. We then test these hypotheses through an empirical investigation that makes use of longitudinal data coming from the Spanish Technological Innovation Panel (PITEC). In particular, with respect to previous studies on the same dataset (Cainelli et al., 2015), we use a wider methodological framework on two more recent non-overlapping waves of it (2012-2010 and 2009-2007).

Interesting results emerge about the prevalence of a "hybrid" mode of eco-innovating, combining the resort to STEI internally with DUIEI externally. Furthermore, such a mode presents important elements of heterogeneity across different EI strategies. For example, in the case of efficiency related EI strategies that purse a reduction in the use of energy, the hybridisation is somehow unbalanced toward the DUIEI mode: an expectedly more important role of internal (non-R&D based) embodied knowledge is actually accompanied by a less expected more relevant weight of synthetic external knowledge. On the other hand, a problematic combination of internal and external knowledge emerges in general, and with respect to all the specific kinds of EIs that we consider.

The rest of the paper is organised as follows. Section 2 illustrates the background literature and our research hypotheses. Section 3 presents the empirical application and Section 4 its results. Section 5 concludes.

2. Background literature and hypotheses

While recognising to knowledge a central role,[2] previous works on EIs drivers have adopted an approach that has limited its focus to "filtering" the validity in the green realm of a number of results obtained by "standard" innovation studies. For example, R&D has been shown to be of greater relevance in the comparison, because of both an alleged superior novelty of EIs with respect to standard innovations (Cainelli et al., 2015) and an entailed higher need of absorptive capacity (Ketata et al., 2014; Ghisetti et al., 2015). A different role between eco- and non-eco innovators has also been found for innovation cooperation (De Marchi, 2012; Cainelli et al., 2015), and for the breadth and depth of external knowledge search (Ghisetti et al., 2015; Ketata et al., 2014), pointing to a higher multidimensionality and systemic nature of EIs (Carrillo-Hermosilla et al. (2010).

On the other hand, it is hard to find a richer kind of analysis that relates the set of requirements entailed by EIs - and their relative importance - to the knowledge portfolio of the eco-innovators, in a sort of "systemic" approach. In particular, no account has been explicitly given so far to whether EIs develop upon specific kinds of learning mechanisms and knowledge-bases, in terms of characteristics like degrees of tacitness, complexity, independence and the like (Malerba and Orsenigo, 1993).

A useful starting point to recover these knowledge aspects is searching for environmental "innovation modes", meant as "firms' [eco-]innovative behaviours [synthetised] into a manageable and interpretable set of typologies of [eco-]innovation practices, strategies and performances." (Evangelista and Vezzani, 2010, p. 1257; our own amendments in squared brackets). While the search for these modes can be generally carried out by combining a wide set of innovation indicators (for a review of this literature see Filippetti, 2011), the focus of the present paper makes more focal the reference to two already crystallised modes of innovating, called "Science, Technology, Innovation" (STI) mode, and "Doing, Using, Interacting Mode" (DUI) (Jensen et al., 2007).

[2] Following the resource-based view of the firm (Wernerfelt, 1984; Barney, 1991), its "natural" extension (Hart, 1995; Hart and Dowell, 2011) and its recent refinements in terms of capabilities theories (Cohen and Levinthal, 1990; Teece et al., 1997), EIs have been linked to specific learning processes (e.g. Ketata et al., 2014), which firms undertake by combining the generation of internal knowledge with the absorption of external one (De Marchi, 2012; De Marchi and Grandinetti, 2013; Cainelli et al., 2015; Ghisetti et al., 2015).

In a nutshell, the two modes differ for their different use of internal and external knowledge. As for STI, in terms of internal knowledge, this is marked by the prevalent use of *R&D based knowledge*, which is generally codified and explicit, as well as potentially global in its reach (Campbell and Güttel, 2005). In external terms, the STI mode mainly relies on knowledge sourced by interacting with epistemic communities of actors (e.g. scholars and inventors) and/or institutions (e.g. universities and labs), organised around specific disciplines. This is mainly, though not exclusively, an *analytical* kind of *knowledge* (Moodysson et al., 2008), which typically leads to a declarative kind of knowledge (Lundvall and Johnson, 1994).

Coming to the DUI mode, internally, it relies on a kind of knowledge that emerges from non-deliberated research efforts (i.e., learning-by) at odds with R&D, and which we could therefore call *non-R&D based knowledge*: typically, this is tacit, implicit and local, but also marked by a certain variety in turn. On the one hand, it can be *embodied* in the firms' investment in physical capital, as well as *embedded* in the human capital they build up with their training investments (Madhavan and Grover, 1988). On the other hand, it can be *disembodied* (as the R&D based one is), but only indirectly related to R&D, if not even unrelated to it, and rather connected to other activities representing important "complementary assets" for innovation to take place, like marketing investments (Rothwell, 1977; Teece, 1986). In external terms, the DUI mode is fuelled by the firm's interaction with its business suppliers, customers, if not even competitors (Lundvall, 1992), yielding a procedural knowledge, which is *synthetic*, as it amounts to the novel combination (i.e. synthesis) of different pieces of existing knowledge (Asheim and Coenen, 2005; Lundvall and Johnson, 1994).

With this STI/DUI distinction in mind, one way to identify the modes in which firms orient their innovative activities towards environmental objectives – in brief, their "EI-modes" – is addressing the use of different forms of internal and external knowledge for the sake of eco-innovating.

We begin our argumentation by focusing on internal knowledge. In this respect, EIs have been found to be more multifaceted than their non-environmental counterparts, requiring firms to master diverse knowledge pertaining to 'design', 'users' involvement', 'product-service', and 'governance' dimensions (Carrillo-Hermosilla et al., 2010). In addition, technologies for the greening of the economy(-ies) in many cases are at an early stage of their life-cycle (Consoli et al., 2015) and their knowledge base is thus quite "complex" (Braungart et al., 2007), making internal STI-like efforts related to R&D quite important for their development. On the other hand, internal DUI-like activities have also emerged to drive EIs. Knowledge embedded in human capital, for example, has been argued to work as a competence-enhancing and motivating factor facilitating the introduction of EIs (Sarkis et al., 2010; Cainelli et al., 2012; Cainelli et al., 2015). Investing in machinery and equipment has also been found relevant (Horbach et al., 2012), in particular with respect to end-of-pipe and integrated cleaner production technologies (Demirel and Kesidou, 2011). Especially in the case of eco-labelling for product EIs, the importance of knowledge connected to marketing efforts has also emerged along with other drivers (e.g. Rennings, 2000; Pujari, 2006). Indeed, the manifold nature of EIs has appeared evident both in general and with respect to diverse environmental objectives, showing that EIs benefit from different internal knowledge sources also when their target is quite specific (Horbach et al., 2012).

All in all, given the typical multidimensionality of EIs, firms that are willing to pursue an innovation strategy in the green realm, either generic or specific, should be prepared to have a wide portfolio of internal knowledge inputs, both with respect to the upstream phases of the innovation process – that is, R&D based – and with respect to the more "halfway" and downstream ones – that is non-R&D based (embodied and disembodied). Accordingly, we advance the following hypothesis:

H1a: *Both R&D and non-R&D based knowledge within the firm drive the implementation of EI strategies*.

Identifying the internal EI-mode would require us to look at the relative importance of R&D and non-R&D based knowledge, in case they are both significant and H1a thus supported.[3] In this last respect, when we look at EI strategies in general, without considering their specific environmental target and its implications in terms of knowledge priorities, we do not have conclusive expectations. On the one hand, as the little research conducted so far on sectoral systems of green innovation has shown (Oltra and Saint Jean, 2009), the knowledge base of the EI regime is quite complex and articulated (Braungart et al., 2007; Winter, 1984; Breschi et al., 2000) and thus apparently more in need of *internal* STI than DUI-like efforts in order to be built up. On the other hand, a prevalence of the internal DUI over the STI mode is suggested by some studies that point to the EI driving role of tacit and procedural knowledge that firms obtain in an embedded/embodied form by investing in their human capital (Sarkis et al., 2010; Cainelli et al., 2012; Cainelli et al., 2015) and in their machinery and plants (Horbach et al., 2012). In the same direction also points the evidence about the importance for EIs of disembodied non-R&D knowledge, like that accruing from marketing investments (e.g. Rennings, 2000; Pujari, 2006). In brief, by looking at generic eco-innovators, without considering the specific environmental target of their innovations, both of our focal modes could be equally possible according to the extant literature.

[3] To be sure, an eventual partial confirmation of H1a – e.g. with R&D (non-R&D) and non-R&D (R&D) based knowledge significant and non-significant, respectively – could already signal the dominance of an internal STEI over a DUIEI mode, or vice-versa.

However, even in absence of clear predictions for STEI vs. DUIEI, we can still expect that one mode of the two would be prevailing at the end. This is actually suggested by the empirical studies on innovation modes, showing that firms cluster around regularities (i.e. modes), not only in their innovation output (e.g. pure technological vs. technological and organisational/marketing (complex) innovators), but also in the kind of knowledge inputs they prioritise (Evangelista and Vezzani, 2010; Filippetti, 2011). We expect that similar regularities can emerge in the case of EIs too, and that eco-innovators attribute different importance to R&D and non-R&D based knowledge, revealing the prevalence of an EI-mode. This can be tested through the following hypothesis:

H1b: *R&D and non-R&D based knowledge have a significantly different importance in determining the internal mode (STEI vs. DUIEI) of implementing EI strategies.*

In testing for H1b, a STEI (DUIEI) emerges internally when, with respect to general EIs, R&D is relatively more (less) important than non-R&D based knowledge. Given the two variants of non-R&D based knowledge that we have identified, the search for an internal EI-mode could result in two further specifications of an eventual STEI (DUIEI) internal mode: a "full internal" specification, should R&D be more (less) important than both embodied and disembodied non-R&D knowledge; an "attenuated internal" specification, in case R&D is more (less) important than either one or the other only.

The arguments that we have developed above can be refined when we refer to more detailed EI strategies. In order to do so, in the following we focus on two main EI typologies: *efficiency related EIs*, represented by process innovations that allow firms to reduce materials and/or energy use; *non-efficiency related EIs*, made up of both process innovations aimed at reducing the environmental damage of the firm's production activities without altering their essential functioning, like end-of-pipe technologies, and product innovations with a positive environmental incidence, like the so-called "green products" and the eco-designed ones. Given the relevance that both R&D and non-R&D based knowledge have for these two kinds of EIs, and the absence of theoretical arguments for supporting any order of importance between the two, this EI distinction is still unable to indicate an internal STEI rather than a DUIE mode for them, like for general EIs (see H1b). However, the same distinction introduces in the analysis some specificitiy in the use of non-R&D based knowledge that, irrespectively from the emerging typical mode, could help in its characterisation.

As far as efficiency related EIs are concerned, firstly, it can be argued that they represent a case of what the literature refers to as embodied technical change (see Hulten, 1992), occurring because of the firm's introduction of more efficient capital goods (machinery and plants), which substitute their previous vintage. In such a substitution, the firm takes stock of the knowledge these capital goods embody to a greater extent than of the (non-R&D based) disembodied knowledge, which can be deemed at most complementary for obtaining their efficiency impact. Second, also with respect to the green realm it can be argued that, in order to get implemented, efficiency related EIs need to be accompanied by important changes in labour composition and skill content (Consoli and Vona, 2015; Consoli et al., 2016). These changes make the knowledge systematization realised by training and adapting human capital more pivotal than the knowledge creation realised by investing in other (non-R&D based) complementary intangibles.

The characterisation of the internal EI mode can be made more specific also when we think of EIs that do not directly increase environmental efficiency, like the adoption of end-of-pipe solutions, and/or the introduction of new green products. Looking at these EIs we expect that non-R&D based embodied knowledge should be less pivotal than the disembodied one, which firms acquire along the downstream stages of the innovation and production processes. This is, first of all, the case of marketing knowledge, which can serve to intercept, attract and satisfies the demand for green products (Lin et al., 2013). Similarly, in the case of end-of-pipe solutions, which differ from cleaner technologies for their application to the extant vintage of capital stock (Frondel et al., 2007), preparation, checking and fine-tuning of existing equipment provide the firm with disembodied knowledge arguably more relevant than the non-R&D embodied one, which is more crucial to move to a new capital vintage.

By combining the previous arguments, the following hypothesis can be tested:

H1c: *In characterising the internal mode (STEI vs. DUIEI) of implementing specific EI strategies, non-R&D based embodied (disembodied) knowledge affects efficiency (non-efficiency) related EIs more than the disembodied (embodied) one.*

Testing for H1c enables us to obtain two possible refinements of the internal analysis. On the one hand, we could better specify an eventual STEI (DUIEI) mode for efficiency and/or non-efficiency related EIs, should R&D be more (less) important than both embodied and disembodied non-R&D knowledge. On the other hand, we could alternatively characterise an eventual “attenuated” STEI (DUIE) mode for the same kinds of EIs, should R&D be more (less) important than either embodied or disembodied non-R&D knowledge only.

Coming to external knowledge, in the light of their systemic and multipurpose nature, EIs have emerged to rely on the combination of a variety of knowledge inputs located outside the firm’s boundaries (Horbach et al., 2013; Cainelli et al., 2015; Ghisetti et al., 2015). On the one hand, analytical knowledge sourced from the “world of science” (e.g. universities and research labs) can be decisive in providing firms with an understanding of the complexity of their prospected EIs (Wagner, 2007; Triguero et al., 2013; Horbach et al., 2012). On the other hand, interacting with the "world of business" can provide the eco-innovator with synthetic knowledge that can be valuable in different respects. Interactions with suppliers and customers can elicit valuable information to: deal with the value chain of a new eco-product, apply recyclability standards, or properly implement green supply chains, especially when looking for EMS certifications (e.g. EMAS) (e.g. Albino et al., 2009; Testa and Iraldo, 2010; Thun and Müller, 2010). Competitors can be an important source of information too. This can be related, for instance, to: demand characteristics that affect the adoption of EI strategies (Horbach et al., 2012; Kesidou and Demirel, 2012), or common regulations (e.g. Marin et al., 2015), and thus responsive innovative solutions (Porter and Van der Linde, 1995) that can be applied by the focal firm too.

All in all, eco-innovators appear to rely on knowledge elicited by interacting both with the world of science and the world of business, and this holds true also when their strategies are specifically oriented toward a certain environmental target (Triguero et al., 2013). On the basis of these arguments, the following hypothesis can be put forward:

H2a: *Both analytical and synthetic knowledge sourced from external actors drive the implementation of EI strategies*.

Like for the internal side, the dominant external mode of EIs should be ascertained by looking at the relative importance of analytical vs. synthetic knowledge, in case they are both significant and H2a thus supported.[4] In doing that, unless we do not focus on the specific environmental realm that eco-innovators target, and on the possible priorities this target entails in the use of external knowledge, we do not have firm predictions. As documented by De Marchi (2012), the evidence on the relative importance of the co-operation between different kinds of external partners is mainly represented by case-studies, with ambiguous implications for the balance between our two external modes (STEI vs. DUIEI) and with limited possibilities of comparison to establish a prevalence. On this basis, we do not feel theoretically well equipped to hypothesise a specific order of importance between the two knowledge kinds when we consider general EIs. However, still looking at the evidence on the firms' tendency to cluster around innovation modes, which also encompass external knowledge sourcing (Filippetti, 2011), we expect that at least such a difference of importance emerges by considering eco-innovators too. To the same expectation also leads the fact that eco-innovators may search for externalities in dealing more - intensively and extensively - with one of the two kinds of

[4] Once again, an indication about the external mode would also emerge should H2a be only partially confirmed, with only one of the two knowledge sources being significant.

partners (i.e. from the world of science or the world of business), as repeated interactions with a specific type of knowledge provider can reduce the problems of cognitive and institutional distances (Boschma, 2005). Accordingly, we expect that:

H2b: *Analytical and synthetic knowledge have a significantly different importance in determining the external mode (STEI vs. DUIEI) of implementing EI strategies.*

Quite evidently, with respect to general EI strategies, a STEI (DUIEI) mode emerges externally when analytical knowledge is found to be relatively more (less) important than synthetic knowledge.

Similarly to the case of internal knowledge, the prediction of H2b can be made more precise with respect to the specific types of EI strategy that we have considered, whose balance between analytical and synthetic knowledge can be more directly ascertained. Indeed, while we do expect that, according to H2a, both kinds of external knowledge are relevant for both efficiency and non-efficiency related EIs, we have theoretical elements to argue that their relative importance varies in the two cases. On the one hand, efficiency related EI strategies, implemented for instance through the adoption of cleaner production technologies, are generally marked by an important degree of radicalness – mainly in terms of novelty of the underlying industrial design and engineering mechanisms – multi-disciplinarity, and complexity – for instance, in terms of logistics and organisational/managerial implications (Carrillo-Hermosilla et al., 2010). With respect to efficiency related EIs, this could make analytical knowledge, obtained from universities and research organisations, more important than the business one accruing through the interaction with suppliers, customers and competitors (Malerba and Orsenigo, 1993). On the other hand, non-efficiency related EIs are arguably more intense of synthetic than analytical knowledge. This is the case, for example, of end-of-pipe solutions, usually amounting to the adoption of add-on devices (e.g. filters) in the extant technologies of the firm, which benefit from the procedural kind of knowledge generally possessed by other firms that might have already developed experience of them (Frondel et al., 2007). Accordingly, interacting with the world of business is presumably more important than interacting with the world of science in this case. A similar conclusion can be reached for new green products. As we said, the role of demand and of sustainability preferences is actually crucial for their introduction, and the customer-based knowledge about their market viability thus turns out to be more important than the STI-based knowledge about their technological/scientific feasibility (Urban and Von Hippel, 1988). EI strategies for the introduction of new green products are also helped by the interaction with the competitors, with respect to which the focal firm will have to position in the search of a product differentiation-kind of competitive advantage (Ambec and

Lanoie, 2008). Finally, the interaction with the world of business has appeared more important than with the world of science also by referring to the partnership with suppliers, which have emerged as strategic to introduce new green products (see De Marchi, 2012, for the a review).

All in all, the following hypothesis can be put forward:

H2c: *In determining the external mode (STEI vs. DUIEI) of implementing specific EI strategies, analytical (synthetic) knowledge affects efficiency (non-efficiency) related EIs more than synthetic (analytical) one*.

A full support to H2c would automatically distinguish efficiency from non-efficiency related EIs also for the dominance of the STEI or DUIEI mode, respectively. To an opposite characterisation would instead lead its full rejection, while a partial confirmation could suggest the sharing of a common mode.

Putting together the internal (H1) and external (H2) sides of our arguments, a further aspect to investigate is the combination of different EI-modes across the firm's boundaries: an aspect of the EI analysis that has been surprisingly neglected so far. The literature on "standard" innovation has recently investigated the benefits of this integration of modes, though mainly within the same realm (i.e. internally or externally), by pointing to a sort of portfolio choice in order to deal with different kinds of innovations (e.g. Parrilli and Elola, 2012; Fitjar and Rodríguez-Pose, 2013; Gonzàlez Pernìa et al., 2015). In our view, the benefits of a "combined" (STI+DUI) mode of innovating found by these studies (for a review, see Parrilli and Heras, 2016) can be originally extended to the case of EIs too. In particular, we expect that the interplay of different mode-specific kinds of knowledge across the firm's boundaries – for example, internal R&D (STEI-specific) and external synthetic (DUIEI-specific) knowledge – could also help in eco-innovating, both in general terms and with respect to specific EI strategies. Indeed, this cross-mode combination of knowledge could enable firms to benefit from more knowledge variety and to better deal with the manifold and systemic nature of EIs (Carrillo-Hermosilla et al., 2010; Ghisetti et al., 2015). On this basis, we expect that:

H3: *The combination of external synthetic (analytical) and internal R&D (non-R&D based) knowledge positively affects the implementation of EI strategies.*

In the absence of prior literature or evidence on this matter, we consider H3 to be rather exploratory in its nature, and we do not advance different expectations for general and specific EI strategies. However, given the likely specificities in terms of knowledge requirements emerged in supporting H1 and H2 (e.g. Triguero et al., 2013; Horbach et al., 2012), we do test H3 both with respect to general and specific (i.e. efficiency and non-efficiency related) EIs, leaving the empirical analysis to speak in favour or against of EI-specific configurations of the interplay between modes across the firm's boundaries.

3. Empirical application

Our empirical analysis is based on data stemming from the Spanish Technological Innovation Panel (PITEC), which is managed by the Spanish National Statistics Institute (INE), the Spanish Foundation for Science and Technology (FECYT) and the Foundation for Technical Innovation (COTEC).[5]

The core sections of the PITEC are consistent with the harmonised CIS questionnaire developed by Eurostat in accordance with the Oslo Manual (OECD, 2005). In particular, since its 2004 wave, the PITEC contains firm-level information on a comprehensive panel of Spanish companies, which includes both large firms and SMEs, and both innovation-oriented and non-innovative firms. The structure of the PITEC is based on yearly waves that cover a three-year period each. In our empirical application we employ two non-overlapping waves, which cover a period extending from 2007 to 2012 (i.e., the 2007-2009 and the 2010-2012 periods).[6] Our working sample is made of around 4,700 manufacturing firms.

The dependent variables of our analysis are built up by looking at the firm's engagement in strategies that, on the basis of an ex-post assessment (i.e. at the end of the three-year period), can be deemed eco-innovative (Cainelli et al., 2015; Antonietti and Marzucchi, 2014). In particular, we first refer to a general binary variable, *Env_Obj*, which takes on value 1 if the firm, when implementing its innovation strategy, has attributed a medium or high importance to the objective of reducing its environmental damage.

We also follow the extant literature and consider environmental objectives as included in the firm's overall portfolio of strategies and linked to other manufacturing technologies (Porter and van der Linde, 1995; Klassen, 2000). Similarly to Antonietti and Marzucchi (2014), we thus create more specific binary dependent variables, by combining the general environmental orientation captured by *Env_Obj* with more detailed objectives. To start with, *Env_Material* and *Env_Energy* take on value 1 in case the focal firm has attributed medium or high importance *also* to a reduction in the use of materials and in the use of energy per unit of output, respectively. Both *Env_Material* and

[5] To the best of our knowledge, ours is the EI-related study based on PITEC data, which uses the most recent waves of the dataset while concentrating on different EI typologies.

[6] We restrict our focus to the period 2007-2012, as previous non-overlapping PITEC waves (e.g. focusing on 2004-2006) do not include the necessary questions to create our dependent variables. Specifically, one question only is available in them with respect to the environmental orientation of the firm's innovation activities, which captures whether they have resulted in a reduced environmental impact and in the improvement of health and safety conditions.

Env_Energy thus capture efficiency related EI strategies: one of the two EI typologies upon which H1c and H2c are based. These EIs can be related to the adoption of technologies - mainly, but not exclusively, cleaner production ones - with such a specific impact (Frondel et al., 2007). Conversely, *Env_Other* refers to EI strategies that have left unaltered the material and energy efficiency of the firm's production process – *Env_Obj not* combined with a medium or high importance of these two objectives – and which could have had different environmental outcomes like, for instance, end-of-pipe solutions or product-like EI strategies.[7] Finally, *Env_Prod* attempts to capture innovation strategies mainly oriented to the introduction of eco-friendly products (Ambec and Lanoie, 2008). *Env_Prod* takes on value 1, in case the general environmental objective (*Env_Obj*) is associated to a medium or high importance attributed to the penetration of new markets or to the increase in the market share, and to low or nil relevance of energy and material efficiency strategies. Both *Env_Other* and *Env_Prod* thus refer to non-efficiency related EIs: the second EI typology upon which we base the test of H1c and H2c.

As far as our focal regressors are concerned, drawing on Section 2, we consider both internal and external sources of knowledge as independent variables.[8] As for the internal realm, we employ three continuous variables, which are created upon the information contained in the PITEC dataset about the firm's investments in innovation activities. First of all, the R&D based knowledge of the firm is captured by *R&D*, which has been created in the following three-step procedure: first, we have summed up the three-year period average expenditures in R&D (i.e. both intramural and extramural) for the sake of internal innovation; we have then divided it by the average number of employees over the same period; and we have finally applied a logarithmic transformation, by adding one in order to avoid dropping the zeros. A second regressor, *Non-R&D_EMB*, aims at capturing the non-R&D based knowledge of embedded/embodied nature. Similarly to *R&D*, this has been created, first, by taking the three-year average of the investments firms have undertaken for the sake of innovation, both in machinery, hardware and software, and in training; we have then divided this average by the mean number of employees; and finally applied the same logarithmic

[7] Due to data limitation, we are unable to single out in a precise way the presence of end-of-pipe technologies with this variable. Ideally, these could have been captured by identifying EI strategies that leave the energy and material efficiency unchanged, and are implemented as a response to environmental regulations. Unfortunately, PITEC data do not distinguish innovation objectives purely related to the compliance with environmental regulations. In fact, available data only identify in a single variable innovation objectives related to health, security and environmental regulations.

[8] It should be noted that PITEC data do not contain specific information on green-knowledge (e.g. environmental R&D or green-related information sourcing). However, as noted by Ghisetti et al. (2015), it would be misleading to separate this latter kind of knowledge from non-green oriented one, in that EIs require firms to have multidisciplinary competencies. In other words, also non-green knowledge is able to enhance the environmental performance of innovation strategies and should be thus included in the analysis.

transformation (adding 1).[9] Finally, *Non-R&D_DISEMB* tries to capture internal knowledge, which is still non-R&D based, but whose production and diffusion does not directly rely on embodiment mechanisms. Still referring to the same section of the questionnaire on innovation investments, the variable reflects the firm's expenditure in activities related to the preparation of production and distribution activities (e.g. tests and feasibility assessments, design and setting of production facilities) and to market penetration (e.g. marketing). In other terms, *Non-R&D_DISEMB* captures "downstream" activities of the firm's value chain, from which knowledge usually emerges in the aftermath of a (tangible and intangible) capital investment ("upstream"), without the need of being "packed" into it. As before, we have taken the three-year average of the expenditures, we have divided this average by the three-year mean number of employees, and we have applied a logarithmic transformation to it (again adding 1 not to lose the zeros).

As for the knowledge sources external to the firm, we refer to the relevant PITEC section and draw on Herstad et al. (2014) in defining two variables. *Analytical* amounts to the number of knowledge providers, irrespectively from their declared importance, from which the firm has reported to acquire innovation-related information, among those in the STI realm, that is: universities, public research organisations, private research institutes and laboratories, and scientific or technical publications. Similarly, *Synthetic* is obtained by summing up the number of knowledge providers referable to the DUI mode to which the focal firm has resorted, still irrespectively from their importance, that is: suppliers, customers, competitors, industry associations, trade fairs and conferences.[10] Our idea in the construction of these last two variables is that the simple "breadth" of the mode-specific knowledge sources external to the firm could be informative of a science-technology rather than doing-using-interacting way of innovating.

The remaining regressors refer to a suitable set of controls, which are included in order to minimise the potential omitted variable bias in our econometric estimations. First, we control for age and size through the two logarithmic variables *LNSize* and *LNAge*, respectively. The two dummies *Group* and *Export* instead control for the firm's belonging to a business group and exposition to international competition, respectively. We also control for additional forms of acquisition of, and exposure to, external knowledge that may affect the adoption of EI strategies, but that are conceptually distinct from our focal regressors about the nature of external knowledge, that is,

[9] While investments in machinery, on the one hand, and in training, on the other hand, would in principle require separate attention, for the sake of our EI-mode investigation, they both represent channels through which firms can get a kind of knowledge, whose embodied/embedded nature makes more related to a DUI, rather than to a STI mode.

[10] Among the list of potential external information sources, PITEC also includes technological centres. Given that it is not possible to establish *a priori* whether to include technological centres either among the analytical or synthetic knowledge providers, we have left this variables out of our baseline results. As a robustness check, we have included the *Tech_centre* variable as an additional regressor in our baseline estimates. Its relation with our dependent variables is always highly insignificant. Results remain stable and are available upon request.

Analytical and *Synthetic*. First, we include in our estimates *Other External*: the three-year average expenditure in the acquisition of external knowledge in the form of patents or licences, still per employee and log-tranformed. Rather than affecting the firm's EI strategies (i.e. EI introduction), this variable is actually more a proxy for the adoption of innovations already introduced by other organisations (i.e. EI adoption/diffusion). Second, following previous studies (e.g. De Marchi, 2012), we control for whether the firm has engaged in formal innovation *Cooperation* agreements, signalling its capacity to go beyond the pure sourcing of external knowledge captured by our two focal external variables. Last, but not least, in order to recognise the fundamental role of the regulatory push/pull effect in the environmental realm, we try to account for the role of regulations and policy actions. In the absence of precise information in this respect, we first employ the dummy *Subsidy*, referring to the firm's receipt of an innovation policy, although data constraints do not enable us to relate this policy to EIs. Furthermore, we include a set of 23 sector dummies at the finest level of disaggregation allowed by the PITEC dataset,[11] which should be able to account (also) for the firm's exposure to sector-specific regulations[12] and to other sector-specific market or technological conditions that may affect the adoption of an EI strategy. Finally, we include a temporal dummy to control for macro-differences between the two waves of the PITEC data that we use.

The main descriptive statistics of the variables we have built up are reported in Table 1. Table 2 shows the correlation matrix among them. While *Analytical* and *Synthetic* appear highly correlated, a VIF test (available on request) excludes this to be a significant issue.

Insert Table 1 around here

Insert Table 2 around here

Given the nature of the dependent variables, our estimation strategy relies on a set of random-effects logit regressions, which thus also account for unobserved heterogeneity. In fact, the high persistence of the EI strategies adopted by the firms in our sample, and the consequent drop of many observations it would entail, does not make fixed-effects estimations suitable in our case.

Our baseline model aims at finding evidence of STEI or DUIEI modes, for EIs in general and for specific EI typologies, by looking at the relevance and relative importance of the internal and external knowledge sources that we have identified. In other words, the test of our first twofold hypotheses (H1a-b-c and H2a-b-c) is based on the estimates of the following model:

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[11] When employing *Env_Prod* as dependent variable, five firms belonging to the "Manufacture of coke and refined petroleum products" sector are dropped due to the absence of values 1 in the dependent variable.
[12] Size-specific regulations are indirectly controlled by *LNSize*.

$$EI_{it} = \alpha + \beta_1 R\&D_{it} + \beta_2 Non\text{-}R\&D\_EMB_{it} + \beta_3 Non\text{-}R\&D\_DISEMB_{it} + \beta_4 Analytical_{it} +$$

$$+ \beta_5 Synthetic_{it} + \mathbf{x}'_{it}\,\gamma + \tau_t + \mu_i + \varepsilon_{it} \qquad (1)$$

where EI_{it} represents our dependent variables and $\mathbf{x}_{it}$ is the vector of our controls.

In order to test for H3, the baseline model is augmented with the interactions between internal and external knowledge sources, obtaining the following specification:

$$EI_{it} = \alpha + \beta_1 Internal\_Knowledge_{it} + \beta_2 External\_Knowledge_{it} + \beta[Internal\_Knowledge_{it}] \text{ x}$$

$$[External\_Knowledge_{it}] + \mathbf{x}'_{it}\,\gamma + \tau_t + \mu_i + \varepsilon_{it} \qquad (2)$$

where $Internal\_Knowledge_{it}$ and $External\_Knowledge_{it}$ are the vectors of internal (i.e. *R&D*, *Non-R&*D*_EMB* and *Non-R&D_DISEMB*) and external knowledge (i.e. *Analytical* and *Synthetic*) sources, respectively. From an operational point of view, and to avoid excessive multi-collinearity, we interact the internal knowledge variables with one external knowledge variable at a time.

As is well known, the structure of the CIS, on which the PITEC questionnaire is based, applies a filter to the questions asked to firms: that is, only innovative firms are required to fill the entire questionnaire. This implies the risk of a selection bias in our case, as the questions on the EI objectives of the companies are posed to innovative firms only (i.e. that have introduced either a product or process innovation, have an ongoing innovation project, or have abandoned an innovation project during the three-year period). In brief, our dependent variables are observable for innovative firms only. In order to address this issue, we carry out a robustness check based on a pooled estimation of a selection model, which accommodates the binary nature of our dependent variables: that is, a heckprobit model (with clustered standard errors).[13] In the absence of reliable exclusion restrictions available in our dataset, we prefer to estimate the selection and outcome equations with the same set of covariates.[14]

[13] To the best of our knowledge, a STATA routine that combines heckprobit in a random-effects panel data regression setting is not available yet.

[14] As is well known, the lack of an exclusion restriction in selection models does not pose identification problems, but may only imply larger standard errors of the parameters (Wooldridge, 2001; Cameron and Trivedi, 2009). The filtering of the PITEC questions also implies that the variables on innovation-related information sourcing and cooperation is available for innovative companies only. However, *Synthetic*, *Analytical* and *Cooperation* have to be employed also in the selection equation, where observations from non-innovative companies are used too. In order to overcome this problem, we impose that the value of these variables is zero for non-innovative firms, given that, for non-innovative companies, innovation cooperation and innovation-related information sourcing are very unlikely to be in place.

4. Results

Table 3 reports the results obtained by estimating Equation 1 with a set of random-effects logit regressions.

Insert Table 3 around here

At the outset, some interesting insights emerge from the effects of the controls included in our econometric specification. *Cooperation* does confirm its importance in the EI realm (e.g. De Marchi, 2012): it increases EIs in general (*Env_Obj*) and, more specifically, the firm's orientation towards technologies that increase energy and material efficiency (*Env_Material* and *Env_Energy*). Looking at the effect of *LNSize*, larger firms have an advantage in pursuing EI strategies, in particular those that affect more directly the efficiency of production processes (*Env_Material* and *Env_Energy*). Smaller firms are, on the contrary, more likely to resort to EI strategies that do not affect such an efficiency, like those that target for instance end-of-pipe or product EIs (*Env_Other* and *Env_Prod*). As for *Subsidy*, we notice that public funding for innovation generally increases EI adoption (*Env_Obj*). However, the funded firms of our sample do not increase their orientation towards cleaner technologies that can be captured by *Env_Material* and *Env_Energy*. They rather target the introduction of green products or downstream solutions that reduce their environmental impact (*Env_Other* and *Env_Prod).*

We now come to the core of our analysis and address, at first, the role of internal knowledge with respect to general EI strategies (*Env_Obj*) (Column 1, first three rows). Results show that the coefficients of *R&D*, *Non-R&D_EMB* and *Non-R&D_DISEMB* are all significant and positive. As expected, and supporting our H1a, a general environmental target in the firm's innovation strategy is associated to a wide knowledge-base, made up of a diversified portfolio of knowledge types (tacit, explicit, embodied and disembodied). Let us notice that the support to H1a extends to more specific EI strategies too: both R&D and at least one of the non-R&D based knowledge inputs (*Non-R&D_EMB* for *Env_Material* and *Env_Energy*; *Non-R&D_DISEMB* for *Env_Other* and *Env_Prod*) are actually positive and significant drivers of our focal EI strategies.

We now turn to the test of H1b: to this aim, we compare the relevance of the different kinds of internal knowledge for general EI strategies. In general, EI strategies benefit from *R&D* more than from the embodied dimension of non-R&D based knowledge (*Non-R&D_EMB*) (the difference in the coefficients is significant at the 5% level). On the contrary, the contribution of R&D is not significantly different from that of *Non-R&D_DISEMB*. These two results lead to a partial support to our H1b. In particular, they suggest that, at least in internal terms, generic EI strategies are adopted following an "attenuated" STEI mode, where R&D is indeed the pivotal investment, but along with other less R&D-centric disembodied knowledge.

As we said while advancing our argumentation in support of H1c, we expect that, in spite of this general result, differences should emerge when looking at specific types of EIs. In particular, we expect differences in the relevance of non-R&D based knowledge sources for what concerns efficiency and non-efficiency related EIs. The results reported in Columns 2-5 of Table 3 confirm our H1c, as it already partially emerged while testing for H1a. On the one hand, it is true that R&D based knowledge plays a driving role with respect to all the specific EI strategies that we consider. On the other hand, when the role of *Non-R&D_EMB* and *Non-R&D_DISEMB* is considered, EI strategies directed to the increase of environmental efficiency, through a reduction in energy (*Env_Energy*) and/or material (*Env_Material*) use (Columns 2 and 3), differ from non-efficiency EIs related to downstream (e.g. end-of-pipe solutions) (*Env_Other*) and green-product innovations (*Env_Prod*) (Column 4 and 5). While efficiency related EIs are not affected by other non-R&D knowledge, but that embodied/embedded in physical and human capital (*Non-R&D_EMB*), non-efficiency related EIs do not rely on other non-R&D knowledge, but the disembodied one related to downstream phases of the innovation process (*Non-R&D_DISEMB*). This is consistent with our expectations. EI strategies aimed at increasing the energy and material efficiency of production processes rely more on an embodied kind of non-R&D knowledge, incorporated in the machinery and equipment that gets ameliorated and/or in the human capital that equips the workforce with suitable skills to operate these ameliorations. This is not the case for the non-efficiency related EI strategies that we consider (e.g. end-of-pipe solutions and new green-products): non-R&D disembodied knowledge, related to marketing, as well as downstream fine-tuning of existing equipment, is actually more important for them.

Given the obtained evidence, we can conclude that specific EI strategies also show some variants with respect to the "attenuated" STEI mode detected for generic ones. For both *Env_Other* (Column 4) and *Env_Prod* (Column 5) a STEI nuance similar to generic EIs emerges. The contribution of *R&D* is still not significantly different from that of *Non-R&D_DISEMB* as in the case of generic EIs. However, R&D matters more than *Non-R&D_EMB*, which is not significantly different from zero. Attenuated, but in a different fashion, is also the STEI mode of *Env_Energy* (Column 3). *R&D* is not significantly different from *Non-R&D_EMB*, but more important than *Non-R&D_DISEMB*, whose effect is not significant this time. Finally, a clearer STEI mode appears in place only for EIs targeting material efficiency (*Env_Material*, in Column 2): the effect of *R&D* is actually statistically greater than that of both *Non-R&D_EMB* (at the 5% level of significance) and *Non-*

R&D_DISEMB (being the latter not significantly different from zero).[15] All in all, with this unique exception of a "neater" case of internal STEI mode for *Env_Material*, for which R&D is actually the key driver, in all the other specific EI strategies and for the generic EI ones, the internal mode of eco-innovating is in fact "STEI attenuated": it entails a pivotal role of R&D, but jointly with at least a selection of sources other than R&D, whose qualification is still EI-specific.

Coming to the external sources (rows four and five in Table 3), both synthetic and analytical knowledge increase the firm's propensity to adopt a generic EI strategy (*Env_Obj,* Column 1), providing a preliminary support to our H2a. This support extends to two out of the four EI strategies that we consider through our dependent variables: both *Analytical* and *Synthetic* have a positive and significant effect for the EI strategies targeting efficiency (i.e. *Env_Material* and Env*_Energy*), while only *Synthetic* is positive and significant in the case of *Env_Other* and *Env_Prod*.

When considering the differential impact of the external knowledge coming from the world of science and the world of business, we find support for H2b. Evidence of a certain external mode of eco-innovating actually emerges from the fact that the effect of *Synthetic* on *Env_Obj* is significantly higher (at the 1% level of significance) than the effect of *Analytical*. Quite interestingly, this points to an external DUIEI mode, in contrast to the internal (attenuated) STEI one we have detected above.

When we turn to the test of our H2c, there emerges a more nuanced evidence on the relative importance of the different sources of external knowledge. As we said in testing for H2a, for the non-efficiency related EIs considered in our analysis – that is, *Env_Other* (Column 4) and *Env_Prod* (Column 5) – only *Synthetic* is significant. *De facto*, synthetic external knowledge is thus more important than the analytical one, providing a first bit of support to H2c. Consistently with the nature of non-efficiency related EIs, procedural and experiential knowledge on how to implement add-on solutions, as well as information on demand, product components and market positioning coming from other business actors (e.g. customers, suppliers and competitors), is the only type of external information that really matters. This is a further interesting result, which qualifies recent evidence on the relevance of the open innovation mode for EIs (Ghisetti et al., 2015).

On the other hand, H2c is contradicted when we look at efficiency related EIs. In fact, as already emerged from the test of H2a, given their degree of radicalness, multi-disciplinarity, and complexity, these EIs rely on a broad range of external sources, which also include information

[15] Although we have commented on the results reported in Table 3, which refer to the coefficients of the random-effects logit regressions and to the differences among them, the picture yields unaltered evidence when we look at the relative marginal effects, by imposing that the random effect (i.e. the unobserved heterogeneity component) is 0. Given the stringency of this approach, we prefer to use the marginal effects as a robustness check. Results remains available upon request.

from the world of science. However, for both *Env_Material* (Column 2) and *Env_Energy* (Column 3), the effect of *Synthetic* is significantly larger than that of *Analytical* (at the 1% level of significant). Somehow unexpectedly, while scientific and technological knowledge is an important input for the adoption of efficiency related EIs, it is from the world of business that the most decisive and operational insights are sourced.

Overall, for what concerns external knowledge for the specific types of EI strategies that we consider, a DUEI mode emerges as prevalent. For *Env_Material* and *Env_Energy,* this mode follows a similar pattern than *Env_Obj,* with both *Synthetic* and *Analytical* having a significantly and positive effects, and the former being larger than the latter (at the 1% level of significance). The same mode emerges also for *Env_Other* and *Env_Prod*: as mentioned, only the synthetic kind of knowledge has a significant and positive effect. The above evidence suggests that, when considering the external knowledge-base of EIs, there are differences related to the specific EIs considered, even if the centrality of external synthetic knowledge holds across the EI strategies. Hence, in external terms at least, a procedural and operational kind of knowledge from the world of business finds place at the side of the more investigated role of codified knowledge, such as that captured by the increasingly popular analysis of green patents (e.g. Verdolini and Galeotti, 2011; Barbieri, 2015; Dechezleprêtre et al., 2015).

In concluding, two different modes emerge across the firm's boundaries in pursuing its EI strategies: an internal STEI mode that, in spite of attenuations and specifications, points to the relevance of R&D; an external DUIE mode that, more neatly and generally, refers to the centrality of business-related knowledge. When we put together the results for the internal and the external knowledge, it emerges that eco-innovators follow a hybrid innovation mode all together, which dichotomically combines an internal STEI with an external DUIEI. The dichotomy is evident – i.e. a clearer STEI internally with a DUIEI externally – only in the case of EI strategies directed to a higher efficiency in the use of materials (i.e. *Env_Material*). In the case of strategies that purse a reduction in the use of energy (i.e. *Env_Energy*), instead, the hybridisation is somehow unbalanced towards a general DUIEI mode: a synthetic external knowledge is accompanied by an internal embodied (and presumably tacit and interacting-based) knowledge, though always along with R&D. In all of the other specific cases, and for EIs in general, the configuration of the hybrid EI-mode that firms follow is dichotomic, but misty.

The combination of the internal and external modes of eco-innovating is indeed an important issue, which deserves closer scrutiny. Before moving to that, however, we need to account for a potential selection bias that might affect our estimates. As we said, we do this by checking for the robustness of the results through a pooled heckprobit estimation of the baseline model (Table 4).

Insert Table 4 around here

First of all, a selection bias actually represents an issue to be considered in our analysis: the two error terms of the selection and outcome equations are correlated (see the Wald test in Table 4). On the other hand, results (both in terms of sign and significance of the coefficients, and of differences between them) are not substantially different from the random-effects logit estimations[16] and they do not alter the extent to which our hypotheses are supported.

Coming to the combination of modes across the firm's boundaries, Table 5 presents the results emerging from the estimation of Eq. 2.

Insert Table 5 around here

Looking at the interaction terms, [17] we observe that none of them turns out to be positively related to general, efficiency related and non-efficiency related EI strategies. On the contrary, we observe a detrimental combination of internal and external knowledge for the sake of these EIs, which contradicts our H3. The significantly negative effect of the interactions between *R&D* (internal-STEI) and *Synthetic* (external-DUIEI) - for both generic and all the specific EI strategies - and between *Non-R&D_DISEMB* (internal-DUIEI) and *Analytical* (external-STEI) - although for *Env_Other* and *Env_Prod* only – actually suggests that a cross-mode interplay of internal and external knowledge leads to negative effects on EIs. Furthermore, the same interplay of knowledge across the firm's boundaries appears counterproductive even within the same mode. This is suggested by the significantly (although weakly) negative effect of the interactions between *Non-R&D_DISEMB* and *Synthetic* within the DUIEI mode – for generic EIs as well as for *Env_Other* and *Env_Prod* – and between *R&D* and *Analytical* within the STEI mode – though for *Env_Material* and *Env_Energy* only.

Overall, a problem of combination of internal and external knowledge seems to be in place, irrespectively from its specificity in terms of innovation modes. In other words, a more general

[16] The only noticeable dissimilarity is the loss of significance in the difference between the coefficients of *R&D* and *Non-R&D_EMB*, for the model that employs *Env_Material* as dependent variable. This difference actually becomes only near-significant (p-value 0.1088).

[17] We here refer to the coefficients of the interaction terms only, as the results emerging from the estimation of Eq. 1 provide a more easily interpretable test of the direct link between our focal regressors and our dependent variables (H1, H2). Estimates based on Eq.1 indeed have only one specification for each dependent variable and are not "confounded" by the indirect effects captured through the interactions. Even so, the direct role of internal and external knowledge appears confirmed, with minor exceptions concerning: *Non-R&D_EMB* for *Env_Material* (Column 1) and *Analytical* for *Env_Other* (Column 2).

issue emerges than that of the problematic combination of the STI and DUI mode, which also other works have detected (e.g. Parrilli and Elola, 2012). In pursuing EI strategies, internal and external sources of knowledge seem to be functional to distinct applicative domains, and apparently require a separate management, as their joint use could pose to firms different kinds of problems (e.g. Ghisetti et al., 2015).

As we have done for the estimates of Eq.1, we check for the robustness of the results for Eq.2 using pooled heckprobit estimates. Still in contrast with our H3, no beneficial interplay between internal and external knowledge is found across different internal and external EI-modes. While many of the negative interactions terms of the previous set of estimates become non-significant, there is still some weak evidence (i.e. for *Env_Other* and *Env_Prod)* of a detrimental interplay between *R&D* and external *Synthetic* knowledge for the sake of EIs. Our argument about the difficulties of combining internal and external knowledge in the environmental realm thus appears confirmed.[18]

In concluding our analysis, we implement two sets of alternative estimates in order to ascertain the robustness of our results with respect to two relevant issues.[19] First of all, we addresses a potential mismatch between our dependent variables and the actual EI strategies followed by the firm, which could emerge because our dependent variables (with the evident exception of *Env_Obj)* are based on the joint presence of an environmental objective and of other innovation goals. An example can help clarify this problem: a firm with *Env_Prod* equal to 1 could have carried out an innovation project giving priority to the reduction of its environmental impact only, along with other distinct innovation projects having the sole aim of penetrating new markets. In other terms, our dependent variable could capture confound the combination of the strategic orientations of distinct projects. In order to control, at least partially, for this possibility, we re-rerun our estimates focusing on small firms only (i.e. with less than 50 employees). It is argued that small firms generally carry out a much more limited number of innovation projects compared to larger companies, given their lower ability to deal with the disadvantages of overstretching the breadth of their projects portfolio (Klingebiel and Rammer, 2014). These disadvantages are indeed particularly strong for small firms, given their limited managerial attention and time (Noteboom, 1994) and their higher financial constraints (Carpenter and Petersen, 2002). Building on these premises, our restricted sample is likely to be made of firms that pursue only one or very few projects at a time. Furthermore, in case

[18] It is relevant to mention that while pooled heckprobit estimates accounts for selection bias issues, they do not account for the unobserved heterogeneity. As we said, this is due to the pooled setting, which we are forced to employ in the absence of established techniques to implement selection models, using a binary dependent variable, in a panel setting. Even if we detect a correlation between the error components of the selection and outcome equations, we do not present these results, which are available from the authors.
[19] For sake of brevity, the results of these last sets of estimates are not presented here in detail, but are also available from the authors upon request.

few concurrent projects are carried out by them, given the technological myopia and high focus on limited products and markets that characterise small firms (Noteboom, 1994), these are likely to be interrelated and aligned in their strategic objectives in terms of EI strategies too (Hamel and Prahalad, 2005). Results substantially confirm the evidence presented above, and the extent to which we support our hypotheses on the relevance (and relative importance) of internal and external knowledge sources (H1 and H2), and on the combination of EI-modes across firm's boundaries (H3).

As far as the second robustness check is concerned, we employ an alternative definition of *Analytical* and *Synthetic* that considers only the relevant information sourced by the focal firm. In particular, the two variables are redefined, by counting only the external sources which are rated as medium or highly relevant for the focal firm's innovation. Emerging results are consistent with those presented above.[20]

5. Conclusions

Which are the most important drivers of EIs? In spite of the increasing attention of the literature, this question is still far from being fully answered. While a first generation of studies has shown that regulatory/legislative drivers of EIs need to be integrated with other non-institutional ones (e.g. Triguero et al., 2013), a second generation is emerging in the attempt of identifying regularities and specifications in the functioning of their techno-economic drivers (e.g. Ketata et al., 2014; Cainelli et al., 2015; Ghisetti et al., 2015), paying particular attention to the resources and capabilities of the firm (e.g. Cainelli et al., 2015; Ghisetti et al., 2015; Herstad et al., 2014). While positioning in this literature, we have made some important contributions to its development. By proposing a systematic approach to the portfolio of the firm's knowledge sources, both internal and external to its boundaries, we have developed some arguments about their significance and relative importance in driving EI strategies. Specifically, we have formulated some research hypotheses in order to detect the presence of characteristic ways of eco-innovating, that is, of EI-modes. In particular, we have extended in the green realm the notable distinction between STI and DUI modes of standard innovations, and addressed their eventual combination across the firm's boundaries. Finally, as a possible major element of novelty with respect to many existing studies, we have carried out the analyses of these arguments by considering also specific EIs rather than generic EI strategies only.

[20] This robustness check does not alter the extent to which we support our hypotheses with a notable exception: H1b is now fully supported, with *R&D* that exerts a significantly higher effect than *Non-R&D_EMB* and *Non-R&D_DISEMB* at the 1% and 10% level, respectively.

In particular, we have distinguished efficiency from non-efficiency related EIs, by referring to innovations targeting material and energy efficiency, rather than downstream innovations (e.g. end-of-pipe solutions) and green products, respectively.

The results we have obtained provide us with novel insights about the knowledge-base of EIs. First of all, the alleged superior complexity of EIs (Carrillo-Hermosilla et al., 2010) makes the firms' reliance on a unique innovation mode not desirable and/or possibly not feasible. Both the STEI and the DUIE modes appear necessary for eco-innovating. However, when considering internal and external knowledge, the relative importance of the two benchmark modes is different. Internally, the STEI mode is prevailing. Externally, there is a higher importance of the DUIEI mode. In other words, firms apparently need to follow a "hybrid" mode in eco-innovating. Metaphorically, eco-innovators are expected to be like "heroes of two worlds", with competencies of both the world of science (and research) and the world of business. Still, the two modes appear in need of separate management, as there seem to emerge problems in combining the relative competences and sources of knowledge across the firm's boundaries. This appears a general result, which contrasts with the complementarity between internal and external knowledge found for standard innovations (Cassiman and Veugelers, 2006), pointing to a possible higher complexity of EIs (Ghisetti et al., 2015).

Quite interestingly, the hybrid EI-mode that firms appear to follow in their generic EIs, takes on heterogeneous specifications across the different kinds of EIs that they pursue. At the outset, these specificities should be carefully considered, by both policy-makers and managers, in searching for specific institutional and organisational leverages, respectively, to spur the adoption of specific EI strategies. In particular, the heterogeneity in the use of knowledge is mainly due to the variety that different EI strategies reveal in terms of internal sources. While R&D based knowledge is a crucial driver for all the EI strategies we analyse, we find differences in the relative importance of non-R&D based knowledge types. EI strategies targeting the reduction of material and energy use rely relatively more on embodied technical change and on the upgrading of skills that allow the workforce to operate environmentally-efficient technologies. On the contrary, non-efficiency related EIs, like end-of-pipe solutions and new green products, rely relatively more on disembodied non-R&D knowledge inputs, like those related to the downstream fine-tuning of existing equipment and to marketing operations. Externally, instead, a DUIEI mode appears more stable across different EI strategies, although differences in external knowledge requirements remain: in particular, it is only with respect to efficiency related EIs that analytical knowledge actually matters, though to a lesser extent than the synthetic one. Targeting specific EI objectives thus mainly require the firm to adapt the use of internal knowledge, while the firm's interface with the outer environment can remain relatively more stable. Indeed, with respect to EIs, creating stable networks of business actors can be more important than crystallising research-based relationships with universities and labs, which however remain relevant with respect to selected EI strategies.

The results we have obtained reveal that supporting EIs is indeed a complex task. Policy actions in this realm should go beyond the simple remediation of market-failures in producing R&D based knowledge and should also stimulate investments for obtaining non-R&D one, although with some apparent lower priority. In order to become eco-innovators firms should also be assisted in overcoming those systemic failures – e.g., the lack of proper interfaces - that hamper their fruitful interactions with both research and, above all, with business partners. In brief, the set of leverages through which firms can be supported in their eco-innovative activities is actually quite broad. This is so unless a specific environmental objective could suggest the focus on specific kinds of knowledge sources and instruments, with a consequent saving of some other ones and an increase in policy efficiency.

Finally, unlike for standard innovations, policy and managerial action should consider with extreme care the support to the firm's development of complementarity between internal and external knowledge. In the case of EIs, such a combination apparently reveals problematic and should suggest a more parcelled support to the firm's knowledge portfolio, still depending on the focal strategy.

This study is not free from limitations, but these can represent opportunity for future research. First of all, we hope that future availability of longitudinal data will permit us to extend the understanding of EI drivers beyond the specific case of Spain, to which we refer. We also hope that future research will be able to employ longer panels to take in direct account an aspect that we have been forced to leave out of our analysis, due to an insufficient number of lags in our EI variables: the persistency of EI behaviours through time. Future data collection and research should also try to include more direct information on the exposure of firms to environmental regulations and policies, an aspect that in firm-level surveys, like PITEC, has been largely overlooked so far. Further research may also consider whether the EI-modes we have identified actually set the stage for the difficult evaluation of the degree of novelty and/or radicalness of EIs (see, for example, Rennings et al., 2013). In particular, more refined data and methodologies for the measurement of radical/incremental EIs will be able to consider whether STEI- rather than DUIEI-based EI strategies lead to more radical and, possibly, more remunerative EIs: an insight from which the original debate on the two modes with respect to standard innovations actually started (Jensen et al., 2007).

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Tables

Table 1 – Descriptive statistics

Variable	Mean	N	SD	p25	p50	p75	Min	Max
Env_Obj	0.532	7858	0.499	0	1	1	0	1
Env_Material	0.349	7858	0.477	0	0	1	0	1
Env_Energy	0.364	7858	0.481	0	0	1	0	1
Env_Other	0.168	7858	0.374	0	0	0	0	1
Env_Prod	0.144	7858	0.352	0	0	0	0	1
R&D*	5555.734	7858	12715.529	526.98	2199.243	5839.096	0	3.62E+05
Non-R&D_EMB*	879.971	7858	3752.012	0	24.841	425.08	0	98783.922
Non-R&D_DISEMB*	563.855	7858	5195.068	0	49.803	312.336	0	2.94E+05
Synthetic	3.117	7858	1.648	2	4	4	0	5
Analytical	2.067	7858	1.565	1	2	4	0	4
LnSize	4.215	7858	1.303	3.271	4.105	5.116	0.693	9.194
LnAge	3.27	7858	0.597	2.89	3.296	3.689	0	5.182
Group	0.442	7858	0.497	0	0	1	0	1
Subsidy	0.374	7858	0.484	0	0	1	0	1
Cooperation	0.35	7858	0.477	0	0	1	0	1
Export	0.861	7858	0.346	1	1	1	0	1
Other External	50.723	7858	833.141	0	0	0	0	54570.254

*Values before log transformation

Table 2 – Correlation matrix

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Env_Obj (1)	1																
Env_Material (2)	0.6867*	1															
Env_Energy (3)	0.7090*	0.8076*	1														
Env_Other (4)	0.4221*	-0.1225*	-0.3401*	1													
Env_Prod (5)	0.3854*	-0.1026*	-0.3106*	0.9132*	1												
R&D** (6)	0.2075*	0.1605*	0.1507*	0.0829*	0.1066*	1											
Non-R&D_EMB** (7)	0.0839*	0.0766*	0.0853*	0.0023	0.0047	-0.0306*	1										
Non-R&D_DISEMB** (8)	0.1303*	0.0976*	0.0947*	0.0520*	0.0817*	0.2311*	0.2180*	1									
Synthetic (9)	0.3961*	0.3413*	0.3389*	0.0926*	0.1098*	0.3273*	0.0791*	0.2099*	1								
Analytical (10)	0.3756*	0.3242*	0.3271*	0.0804*	0.0894*	0.3410*	0.0697*	0.1599*	0.6959*	1							
LnSize (11)	0.1712*	0.1912*	0.2042*	-0.0342*	-0.0201	0.0035	0.0529*	0.0084	0.1297*	0.1963*	1						
LnAge (12)	0.0678*	0.0484*	0.0692*	0.0015	0.0033	-0.0087	-0.0111	0.0024	0.0379*	0.0670*	0.3208*	1					
Group (13)	0.1171*	0.1332*	0.1401*	-0.0239*	-0.01	0.0793*	0.0341*	0.0098	0.0758*	0.1446*	0.5402*	0.0787*	1				
Subsidy (14)	0.1614*	0.1285*	0.1251*	0.0544*	0.0701*	0.3286*	0.1058*	0.1503*	0.2181*	0.3032*	0.1584*	0.0333*	0.1139*	1			
Cooperation (15)	0.1922*	0.1619*	0.1714*	0.0360*	0.0473*	0.2515*	0.1016*	0.1358*	0.2441*	0.3530*	0.1912*	0.0536*	0.1922*	0.3521*	1		
Export (16)	0.0807*	0.0677*	0.0686*	0.0194	0.0373*	0.1464*	0.0176	0.0848*	0.1193*	0.1276*	0.2115*	0.1405*	0.1277*	0.1194*	0.0974*	1	
Other External (17)	0.0408*	0.0400*	0.0420*	0.0004	0.0097	0.0263*	0.1293*	0.1331*	0.0545*	0.0676*	0.0881*	0.0329*	0.0584*	0.0844*	0.0898*	0.0460*	1

*, denotes a 5% level of significance. ** Values before log transformation

Table 3 – Random-effects logit estimations (baseline model)

	(1) Env_Obj	(2) Env_Material	(3) Env_Energy	(4) Env_Other	(5) Env_Prod
R&D	0.0847***	0.0876***	0.0612***	0.0534***	0.0895***
	(0.0162)	(0.0183)	(0.0178)	(0.0185)	(0.0216)
Non-R&D_EMB	0.0385***	0.0400***	0.0494***	-0.009	-0.0141
	(0.013)	(0.0138)	(0.0136)	(0.0137)	(0.015)
Non-R&D_DISEMB	0.0531***	0.0221	0.0207	0.0362**	0.0691***
	(0.0142)	(0.0154)	(0.015)	(0.0154)	(0.0169)
Synthetic Knowledge	0.5964***	0.6123***	0.5933***	0.1766***	0.2389***
	(0.0413)	(0.0467)	(0.0448)	(0.0401)	(0.0446)
Analytical Knowledge	0.2641***	0.2617***	0.2624***	0.0229	-0.0126
	(0.0405)	(0.0423)	(0.0419)	(0.0441)	(0.0478)
Year_2012	0.0096	0.0764	0.1132	-0.1386*	-0.1216
	(0.0699)	(0.0719)	(0.0711)	(0.0773)	(0.0835)
LNSize	0.2533***	0.3403***	0.3617***	-0.1415***	-0.1087**
	(0.0464)	(0.05)	(0.0491)	(0.0489)	(0.0533)
LNage	0.0891	-0.0622	0.0364	0.077	0.0568
	(0.0812)	(0.0865)	(0.0843)	(0.0848)	(0.0918)
Group	0.0554	0.1845	0.1737	-0.1399	-0.0893
	(0.1061)	(0.1135)	(0.1113)	(0.1142)	(0.1255)
Subsidy	0.2124**	-0.017	0.0115	0.2383**	0.2824***
	(0.0958)	(0.1009)	(0.0982)	(0.1002)	(0.1075)
Other External	-0.007	0.0041	0.0017	-0.0129	0.003
	(0.0347)	(0.0361)	(0.0355)	(0.0386)	(0.0412)
Cooperation	0.3385***	0.2443**	0.2857***	0.0312	0.0513
	(0.0988)	(0.1015)	(0.0995)	(0.1036)	(0.1115)
Export	-0.0732	-0.0851	-0.1154	0.109	0.2332
	(0.1279)	(0.1417)	(0.1409)	(0.1377)	(0.1545)
_cons	-5.4722***	-6.8165***	-6.7666***	-3.4243***	-4.9096***
	(0.4717)	(0.5501)	(0.533)	(0.5017)	(0.588)
N firm obs	7858	7858	7858	7858	7853
N firm-period obs	4729	4729	4729	4729	4726
Wald X^2 [36]	707.01 ***	602.91 ***	609.83 ***	152.49***	178.56***

Robust standard errors (clustered by firm) in parentheses. ***. **. * denote 1%. 5% and 10% levels of significance. respectively. Sector dummies included

Table 4 – Pooled heckprobit estimations

	(1) Env_Obj	(2) Env_Material	(3) Env_Energy	(4) Env_Other	(5) Env_Prod
Outcome Equation					
R&D	0.0294***	0.0296***	0.0220***	0.0140*	0.0277***
	(0.0065)	(0.007)	(0.0069)	(0.0075)	(0.0083)
Non-R&D_EMB	0.0154***	0.0163***	0.0202***	-0.0074	-0.0081
	(0.0052)	(0.0053)	(0.0053)	(0.0056)	(0.0059)
Non-R&D_DISEMB	0.0159***	0.0055	0.0052	0.0116*	0.0247***
	(0.0056)	(0.0059)	(0.0058)	(0.0063)	(0.0066)
Synthetic Knowledge	0.1983***	0.2076***	0.2008***	0.0336**	0.0616***
	(0.015)	(0.0167)	(0.0164)	(0.0166)	(0.0177)
Analytical Knowledge	0.1153***	0.1021***	0.1041***	0.0151	0.0024
	(0.0156)	(0.0158)	(0.0158)	(0.0178)	(0.0187)
Year_2012	0.0262	0.0494*	0.0595**	-0.0410	-0.0326
	(0.0269)	(0.0267)	(0.0267)	(0.0311)	(0.0322)
LNSize	0.0972***	0.1301***	0.1377***	-0.0594***	-0.0448**
	(0.0177)	(0.0183)	(0.018)	(0.0195)	(0.0204)
LNage	0.0303	-0.0265	0.0111	0.0263	0.0166
	(0.0314)	(0.0321)	(0.0316)	(0.0343)	(0.0355)
Group	0.0169	0.0614	0.0636	-0.0563	-0.0378
	(0.0411)	(0.0425)	(0.0421)	(0.0458)	(0.0484)
Subsidy	0.0525	-0.0088	-0.0212	0.0915**	0.1111***
	(0.0376)	(0.0385)	(0.0379)	(0.041)	(0.0424)
Other External	-0.0037	0.0005	0.0012	-0.0065	-0.0001
	(0.0134)	(0.0139)	(0.0136)	(0.0157)	(0.0161)
Cooperation	0.1024***	0.0613	0.0893**	-0.0009	0.0053
	(0.0386)	(0.0387)	(0.0384)	(0.0423)	(0.0441)
Export	-0.0484	-0.0628	-0.0734	0.0452	0.0994*
	(0.0507)	(0.0543)	(0.0538)	(0.056)	(0.0598)
_cons	-1.9218***	-2.4248***	-2.4192***	-1.1259***	-1.6656***
	(0.172)	(0.1905)	(0.1869)	(0.1988)	(0.2229)
Selection Equation					
R&D	0.2206***	0.2232***	0.2205***	0.2228***	0.2232***
	(0.0121)	(0.0122)	(0.0122)	(0.0121)	(0.0122)
Non-R&D_EMB	0.2716***	0.2790***	0.2776***	0.2698***	0.2740***
	(0.0201)	(0.0203)	(0.0202)	(0.0197)	(0.02)
Non-R&D_DISEMB	0.2068***	0.2072***	0.2084***	0.2083***	0.2080***
	(0.024)	(0.0243)	(0.0242)	(0.024)	(0.0243)
Synthetic Knowledge	6.8664***	6.8666***	6.8665***	6.8664***	6.8664***
	(0.1967)	(0.2488)	(0.2344)	(0.1214)	(0.1403)
Analytical Knowledge	5.7470***	5.7470***	5.7470***	5.7470***	5.7470***
	(0.167)	(0.1986)	(0.1975)	(0.1708)	(0.1858)
Year_2012	-0.7956***	-0.8018***	-0.8042***	-0.7934***	-0.8028***
	(0.0677)	(0.0684)	(0.068)	(0.0683)	(0.0688)
LNSize	0.1655***	0.1699***	0.1713***	0.1719***	0.1740***
	(0.03)	(0.0301)	(0.0304)	(0.0298)	(0.0301)

LNage	0.0717	0.0681	0.0761	0.0670	0.0688
	(0.0617)	(0.062)	(0.0623)	(0.0616)	(0.0621)
Group	0.0238	0.0252	0.0331	0.0141	0.0134
	(0.0807)	(0.0815)	(0.0812)	(0.0809)	(0.0816)
Subsidy	0.7697***	0.7820***	0.8106***	0.7455***	0.7602***
	(0.1967)	(0.1923)	(0.201)	(0.1884)	(0.1927)
Other External	0.0759	0.0791	0.0805	0.0763	0.0799
	(0.0944)	(0.0962)	(0.0956)	(0.0951)	(0.0969)
Cooperation	7.0351***	7.0350***	7.0350***	7.0351***	7.0350***
	(0.2055)	(0.2557)	(0.249)	(0.2075)	(0.2204)
Export	0.1674**	0.1762**	0.1664**	0.1747**	0.1770**
	(0.0766)	(0.0771)	(0.0772)	(0.076)	(0.0766)
_cons	-2.2624***	-2.2716***	-2.3041***	-2.3010***	-2.3161***
	(0.2863)	(0.2885)	(0.2915)	(0.2881)	(0.2936)
N	10240	10240	10240	10240	10240
Censored	2382	2382	2382	2382	2382
Uncensored	7858	7858	7858	7858	7858
Wald X^2 [36]	1000.81***	797.01***	831.95***	116.6***	828.98***
Wald test ρ =0 [1]	36.43***	22.92***	15.15***	43.07***	20.84***

Robust standard errors (clustered by firm) in parentheses. ***. **. * denote 1%. 5% and 10% levels of significance. respectively. Sector dummies included

Table 5 – Random-effects logit estimations (including interactions)

	Env_Obj		Env_Material		Env_Energy		Env_Other		Env_Prod	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
R&D	0.1665***	0.1033***	0.1795***	0.1262***	0.1561***	0.1017***	0.1471***	0.0726***	0.1699***	0.1040***
	(0.0285)	(0.0217)	(0.0374)	(0.0268)	(0.0346)	(0.0256)	(0.0311)	(0.0244)	(0.0369)	(0.0287)
Non-R&D_EMB	0.0493*	0.0547***	0.0467	0.0710***	0.0650*	0.0806***	0.0331	0.0055	0.0249	0.0028
	(0.0290)	(0.0211)	(0.0370)	(0.0244)	(0.0354)	(0.0242)	(0.0314)	(0.0232)	(0.0363)	(0.0260)
Non-R&D_DISEMB	0.1067***	0.0676***	0.0326	-0.0005	0.0563	0.0066	0.0917***	0.0862***	0.1347***	0.1155***
	(0.0315)	(0.0237)	(0.0413)	(0.0281)	(0.0393)	(0.0277)	(0.0344)	(0.0266)	(0.0384)	(0.0297)
Synthetic	0.8380***	0.5892***	0.8180***	0.6062***	0.8360***	0.5852***	0.4765***	0.1624***	0.5154***	0.2273***
	(0.0751)	(0.0416)	(0.0857)	(0.0472)	(0.0816)	(0.0454)	(0.0759)	(0.0408)	(0.0877)	(0.0454)
Analytical	0.2657***	0.3885***	0.2615***	0.4079***	0.2626***	0.4316***	0.0246	0.2057**	-0.0118	0.1448
	(0.0404)	(0.0818)	(0.0422)	(0.0913)	(0.0419)	(0.0889)	(0.0437)	(0.0914)	(0.0473)	(0.1058)
Synthetic*R&D	-0.0295***		-0.0295***		-0.0311***		-0.0336***		-0.0279***	
	(0.0086)		(0.0103)		(0.0097)		(0.0090)		(0.0104)	
Synthetic*Non-R&D_EMB	-0.0031		-0.0018		-0.0043		-0.0124		-0.0111	
	(0.0082)		(0.0097)		(0.0093)		(0.0084)		(0.0096)	
Synthetic*Non-R&D_DISEMB	-0.0164*		-0.0031		-0.0101		-0.0163*		-0.0190*	
	(0.0088)		(0.0108)		(0.0103)		(0.0093)		(0.0102)	
Analytical*R&D		-0.0114		-0.0192*		-0.0209**		-0.0126		-0.0090
		(0.0092)		(0.0104)		(0.0101)		(0.0103)		(0.0120)
Analytical*Non-R&D_EMB		-0.0074		-0.0129		-0.0130		-0.0058		-0.0068
		(0.0084)		(0.0089)		(0.0088)		(0.0086)		(0.0095)
Analytical*Non-R&D_DISEMB		-0.0066		0.0093		0.0059		-0.0216**		-0.0195*
		(0.0090)		(0.0098)		(0.0097)		(0.0096)		(0.0106)

Year_2012	0.0054	0.0093	0.0748	0.0788	0.1109	0.1151	-0.1446*	-0.1417*	-0.1246	-0.1239
	(0.0700)	(0.0698)	(0.0720)	(0.0719)	(0.0713)	(0.0711)	(0.0773)	(0.0774)	(0.0834)	(0.0836)
LNSize	0.2581***	0.2551***	0.3431***	0.3412***	0.3665***	0.3635***	-0.1376***	-0.1381***	-0.1055**	-0.1056**
	(0.0466)	(0.0464)	(0.0502)	(0.0500)	(0.0494)	(0.0492)	(0.0488)	(0.0490)	(0.0532)	(0.0535)
LNage	0.0894	0.0880	-0.0644	-0.0664	0.0351	0.0322	0.0760	0.0782	0.0566	0.0579
	(0.0814)	(0.0813)	(0.0868)	(0.0866)	(0.0848)	(0.0844)	(0.0848)	(0.0852)	(0.0917)	(0.0922)
Group	0.0556	0.0541	0.1865	0.1830	0.1756	0.1722	-0.1408	-0.1425	-0.0891	-0.0909
	(0.1063)	(0.1062)	(0.1138)	(0.1137)	(0.1119)	(0.1116)	(0.1142)	(0.1144)	(0.1254)	(0.1258)
Subsidy	0.2228**	0.2215**	-0.0080	-0.0059	0.0219	0.0251	0.2519**	0.2521**	0.2914***	0.2921***
	(0.0956)	(0.0960)	(0.1009)	(0.1012)	(0.0983)	(0.0984)	(0.0995)	(0.1002)	(0.1069)	(0.1075)
Other External	-0.0039	-0.0057	0.0057	0.0044	0.0036	0.0025	-0.0091	-0.0099	0.0067	0.0059
	(0.0347)	(0.0346)	(0.0362)	(0.0361)	(0.0355)	(0.0355)	(0.0386)	(0.0386)	(0.0412)	(0.0412)
Cooperation	0.3559***	0.3498***	0.2576**	0.2540**	0.3027***	0.2978***	0.0534	0.0474	0.0693	0.0637
	(0.0988)	(0.0989)	(0.1014)	(0.1016)	(0.0997)	(0.0997)	(0.1031)	(0.1037)	(0.1109)	(0.1117)
Export	-0.0710	-0.0752	-0.0853	-0.0816	-0.1188	-0.1137	0.1120	0.0998	0.2388	0.2259
	(0.1293)	(0.1284)	(0.1428)	(0.1421)	(0.1424)	(0.1413)	(0.1385)	(0.1384)	(0.1550)	(0.1551)
_cons	-6.1539***	-5.6698***	-7.4520***	-7.0837***	-7.5203***	-7.0671***	-4.2782***	-3.7349***	-5.7416***	-5.2068***
	(0.5115)	(0.4846)	(0.6035)	(0.5666)	(0.5825)	(0.5499)	(0.5504)	(0.5201)	(0.6433)	(0.6073)
N firm obs	7858	7858	7858	7858	7858	7858	7858	7858	7853	7853
N firm-period obs	4729	4729	4729	4729	4729	4729	4729	4729	4726	4726
Wald X^2 [39]	698.28***	704.89***	593.14***	599.92***	598.06***	606.5***	160.23***	156.08***	178.34***	178.76***

Robust standard errors (clustered by firm) in parentheses. ***. **. * denote 1%. 5% and 10% levels of significance. respectively. Sector dummies included